The SAMSON Project – Cluster Flight and Geolocation with Three Autonomous Nano-satellites

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Meidad Pariente
Spaceialist LTD
Definition

Distributed Space System (DSS) - An end-to-end system including two or more space vehicles and a cooperative infrastructure for data acquisition, processing, analysis and distribution.
SAMSON
Space Autonomous Mission for Swarming and Geolocation with Nano-satellites
Heritage

Gurwin-Techsat Micro-Satellite

Motivation

- **Mission**
  - World-first 3 Cubesat cluster
  - Geolocation demonstration

- **Technology Implementation**
  - Technion-developed formation-flying algorithms
  - Among first nano-satellite propulsion systems

- **Hands-on experience for Technion students**

- **Promote collaboration with Israel’s space industry**

- **International and national visibility**
Samson System

User
Ground
Emitter

UGE

Ground
Station

GMOC

Geolocation
Mission
Operations
Center
Geolocation Mission

- **Goal**: Geolocate a cooperative transmitter within 100 m.
- Each satellite receives the signal at a different time
- Measurements:
  - **Time Difference of Arrival (TDOA)**:
    \[
    \Delta t_{21} = \frac{1}{c} \|s_2 - u\| - \frac{1}{c} \|s_1 - u\|
    \]
    ★ TDOA accuracy: 100 nsec
  - **Frequency Difference of Arrival (FDOA)**:
    \[
    \Delta f_{21} = \frac{f_0}{c} \left( \frac{(s_2 - u) \cdot v_2}{\|s_2 - u\|} - \frac{(s_1 - u) \cdot v_1}{\|s_1 - u\|} \right)
    \]
    ★ FDOA accuracy: 0.5 Hz
- Geolocation based on least-squares processing
Geolocation: Preliminary Simulation Results

Linear Geometry

Triangular Geometry

Clock error = 100 ns,
Frequency error = 0.5 Hz

\[ a = 6984 \text{ km}, \ e = 0, \ i = 51.5^\circ \]
Geolocation Experiment

Results:

<table>
<thead>
<tr>
<th>Emitter Number</th>
<th>Error [m]</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.033</td>
</tr>
<tr>
<td>2</td>
<td>0.0773</td>
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<tr>
<td>3</td>
<td>0.0414</td>
</tr>
<tr>
<td>4</td>
<td>0.27*</td>
</tr>
<tr>
<td>5</td>
<td>0.1839</td>
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</tbody>
</table>

* Only 7 measurements

DSSL facilities:
- Air Table
- Robots (simulated satellites)
- 5 Ultrasonic emitters on ceiling
- A Camera to locate robots positions on table
- TOA measurement system
Cluster Flight: Control Algorithm

Cluster control requirement:
\[ 100 \text{ m} \leq \Delta r \leq 250 \text{ Km} \]

Goal: Minimize fuel consumption for whole cluster
\[ \Delta V \propto |a_1 - a_0| + |a_2 - a_0| + |a_3 - a_0| \]
\[ a_0 = \frac{\min(a_i) + \max(a_i)}{2} \]

Set S1 SMA to \( a_0 \)
Alternate SMAs of S2 and S3 around \( a_0 \)
Cluster Flight: Preliminary Simulations Results

One year simulation, 50 m gap, Thruster: 0.02 [N], 5 / 26 [s] firing cycle

Propulsion performance:

Semi-major axis

Range between satellites

satellite – 1
\[ total \Delta V = 0 \left[ \frac{m}{sec} \right] \]
satellite – 2
\[ total \quad pulses = 826 \]
\[ total \quad time = 1289.5[sec] \]
\[ total \quad \Delta V = 2.579 \left[ \frac{m}{sec} \right] \]
satellite – 3
\[ total \quad pulses = 645 \]
\[ total \quad time = 670.7[sec] \]
\[ total \quad \Delta V = 1.3413 \left[ \frac{m}{sec} \right] \]
SAMSON Satellite

Designed by V. Balabanov – Asher Space Research Institute
## Sub-Systems Selection

<table>
<thead>
<tr>
<th>System</th>
<th>Subsystem</th>
<th>Alternatives</th>
<th>Alternatives</th>
<th>Alternatives</th>
<th>Alternatives</th>
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<tbody>
<tr>
<td>Structure</td>
<td>Chassis</td>
<td>ISIS 6U standard</td>
<td>IAI New design</td>
<td>Technion New Design</td>
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<td></td>
<td>Harness</td>
<td>ISIS tailored</td>
<td>IAI tailored</td>
<td>Technion tailored</td>
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<td>Fasteners</td>
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<td>IAI tailored</td>
<td>Technion tailored</td>
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<td>Thermal HW</td>
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<tr>
<td>Computer</td>
<td>Motherboard</td>
<td>Pumpkin rev E</td>
<td>No need</td>
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<tr>
<td></td>
<td>On Board Computer</td>
<td>Pumpkin PPM A1 with T'is MSP430F1612</td>
<td>GomSpace 712C</td>
<td>NanoMind 31us</td>
<td>IAI RAMONCHIPS LEON3</td>
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<tr>
<td>Electric Power Supply</td>
<td>EPS</td>
<td>ClydeSpace CS-XUEPS2-42A</td>
<td>GomSpace 31us</td>
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<td>PDU</td>
<td>ClydeSpace CN-SWT-0035-CS</td>
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<td>GomSpace 514</td>
<td>ABSL Inklajn</td>
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<td>Solar Panels</td>
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<td>GomSpace</td>
<td>IAI</td>
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<tr>
<td>AOCS</td>
<td>MTR Card</td>
<td>ISIS iMTQ</td>
<td>GomSpace</td>
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<tr>
<td></td>
<td>MGM</td>
<td>Maryland Aerospace MAI-400 Full Arazim</td>
<td>No Need</td>
<td></td>
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<tr>
<td></td>
<td>RW</td>
<td>Maryland Aerospace MAI-400 Full Sinclair</td>
<td>SSBV Cubesat Sun Sensor</td>
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<tr>
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<td>CSS</td>
<td>Maryland Aerospace MAI-400 Full</td>
<td>SSTL SGR-05U</td>
<td>SSBV GPS</td>
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<td>GPS</td>
<td>Rokar</td>
<td>SSTL SGR-05U</td>
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<td>GPS Ant</td>
<td>Rokar</td>
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<td>Communication</td>
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<td>ISIS UVTCR</td>
<td>GomSpace</td>
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<td>GomSpace</td>
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<tr>
<td></td>
<td>Ant Module</td>
<td>ISIS</td>
<td>GomSpace</td>
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<td>Elbit</td>
<td>Elta</td>
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<td>P/L Patch Antenna</td>
<td>Elbit</td>
<td>Elta</td>
<td>ISIS HISPICO</td>
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<tr>
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<td>Atomic Clock</td>
<td>Accubeat</td>
<td>No need</td>
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<tr>
<td></td>
<td>Tank</td>
<td>Rafael</td>
<td>No need</td>
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<tr>
<td></td>
<td>Heaters</td>
<td>Rafael</td>
<td>No need</td>
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<tr>
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<td>Pipe + Thrusters</td>
<td>Rafael</td>
<td>Mars-Space</td>
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</tr>
</tbody>
</table>
In-Orbit Power Constraints

Power production sensitivity

Power balance during mission (sun-pointing)

Resolving power constraints:
- **Nadir-Pointing** during:
  - Geolocation mission
  - Cluster control
  - Ground Station access
- **Sun-Pointing** during cruise
Launch

- Orbit requirements:
  - Circular orbit, 500 to 800 km altitude
  - Inclination of above 35°
  - Ascending nodes: \(| \Omega_1 - \Omega_{2,3} | > 0.2°\)

- 6-Pod interface (x3)

- Single launch

- Desired: a launcher with a maneuvering upper stage (e.g. FREGAT, BLOK, and DRAGON)

- “A-train concept” adapted for nano-satellites

- Each nanosatellite will be released from the launcher at a different time and with a small Δv

- There is no designated launcher to date
SAMSON Program

- Mission Definition (Jan 2012)
- System Requirements Review (Mar 2012)
- Preliminary Design Review (Sep 2012)
- Critical Design Review (Mar 2013)
- Integration Readiness Review (Jun 2013)
- Testing Readiness Review (Aug 2014)
- Launch (Jan 2015)
Acknowledgments

- European Research Council - “Flight Algorithms for Disaggregated Space Architectures (FADER)”
- Boaz Shuval
Thank You!

Questions?